United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

Research Paper
PSW-176

Species Trials for Biomass Plantations in Hawaii: a first appraisal

Thomas H. Schubert Craig D. Whitesell

The Authors:

THOMAS H. SCHUBERT is a research silviculturist with the BioEnergy Development Corporation, Hilo, Hawaii. He earned a bachelor of science degree (1953) in forestry at New York State University College of Forestry, Syracuse, and a master of forestry degree (1955) and doctoral degree (1959) in biology at Harvard University. **CRAIG D. WHITESELL** heads up the Pacific Southwest Station's forestry research in the American Pacific Islands, and is stationed in Honolulu, Hawaii. He earned a bachelor of science degree (1951) in forestry at West Virginia University, and a master of forestry degree (1954) at Duke University.

Acknowledgments:

The study reported herein was funded in part by the U.S. Department of Energy under Subcontract 9061.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

August 1985

Species Trials for Biomass Plantations in Hawaii: a first appraisal

Thomas H. Schubert Craig D. Whitesell

CONTENTS

IN BRIEF . . .

Schubert, Thomas H.; Whitesell, Craig D. **Species trials for biomass plantations in Hawaii: a first appraisal.** Res. Paper PSW-176. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1985. 13 p.

Retrieval Terms: Eucalyptus, Albizia, Acacia, species trials, biomass, subtropical, Polynesia, Hawaii

Species trials have been conducted in Hawaii since the 1870's. Many introduced species have been successfully established and harvested, whereas native species have failed in numerous reforestation projects. Since the early 1960's silviculture research concentrated on developing methodology for establishing and developing forest stands for timber production.

More recently, attention has focused on developing management practices that will maximize the economic returns from intensively cultured, short-rotation forest plantations. The projected rotation age is 6 to 8 years. Species adaptability trials were begun in 1979 by the BioEnergy Development Corp., a C. Brewer Company subsidiary, in cooperation with the Forest Service, U.S. Department of Agriculture. The objective is to identify tree species that will grow rapidly on various sites, including scrub forest lands, abandoned canefields, and degraded lands.

This paper provides a progress report on the performance of selected species 24 to 60 months after outplanting. Short drought periods, accompanied by increased solar radiation, resulted in increased growth in the trials established on normally high rainfall areas. However, extended droughts of one-half to 2 years' duration adversely affected tree growth.

Nine species trials were established on five sub-tropical sites, with 28 species appraised at one or more locations. On these sites, elevations ranged from 425 m (1400 ft) to 650 m (2125 ft), and rainfall ranges from 1800 mm (70 inches) to >5000 mm (>200 inches). Soils developed from volcanic material; some were fairly deep, others shallow and rocky.

The trials were laid out in a randomized complete block design, usually with four replications. Three to 15 species were included in each trial. Spacing ranged from 1.5 to 1.5 m (5 by 5 ft) to 2.0 by 2.0 m (6.6 by 6.6 ft). Usually, 100 measurement trees of each species were planted in each trial.

With a few exceptions, eucalyptus proved best adapted to the BioEnergy sites available for biomass production. The mean annual height growth of *Eucalyptus grandis, E. saligna,* and *E. globulus* averaged 3 m (10 ft); with high survival. *Albizia falcataria,* planted on four sites, did very well also, with a mean annual height growth of 3 m (10 ft). *Acacia mangium* grew better on well-drained sites, but usually produced multiple stems. Species whose performance was unsatisfactory include the native *Acacia koa, A. melanoxylon, Leucaena leucocephala,* two *Sesbania* species, *Pinus elliottii* and *Mimosa scabrella.* Most failures and unsatisfactory performances relate to harsh site conditions, such as low soil fertility, droughts, and high winds.

Eucalyptus grandis and *E. saligna* are recommended on well-drained, high rainfall areas; and *E. robusta* on poorly-drained, high rainfall areas. *Eucalyptus globulus* should be considered for planting on drier sites, especially on higher elevation zones. *Albizia falcataria* and *Acacia* grow well on very infertile sites and should be considered for interplanting with eucalyptus, as both are nitrogen-fixing legumes.

INTRODUCTION

The State of Hawaii depends on imported petroleum for more than 90 percent of its energy needs. Development of local alternative energy sources would reduce this heavy dependence on imported energy, and would retain the funds spent within the local economy.

With its year-round subtropical climate, Hawaii provides an ideal environment for biomass production. Its sugar factories have for many years burned bagasse (the plant fiber remaining after sugarcane processing) to produce steam and electricity for internal needs, with excess electricity sold to local power company utilities. However, bagasse must be supplemented by imported fuel oil when the sugar mills are periodically shut down. Energy production must be maintained in order to honor contractual commitments to the power company to supply power into the local grid.

A local source of biomass could be wood fiber from intensively cultured, short-rotation tree farms. In 1978, C. Brewer and Company, Ltd. and the Forest Service, U.S. Department of Agriculture prepared a research and development proposal to explore the production of biomass energy from eucalyptus trees on the island of Hawaii. This proposal was accepted for funding by the U.S. Department of Energy, and early in 1979 work was begun by the Company's wholly-owned subsidiary BioEnergy Development Corp.

This paper reports the results of the first 5 years of research to identify the tree species best suited for biomass production on various sites on the island of Hawaii.

RESEARCH ON BIOMASS PRODUCTION

Systematic planting of eucalyptus and other introduced species began in the 1870's in Hawaii, to provide protection for denuded watersheds. The first commercial stand of eucalyptus was established in 1882 to provide fuel for a sugarcane plantation (LeBarron 1962). By 1970, of 13,750 ha (34,000 acres) of commercial forest planting, over half of this amount were in eucalyptus (Metcalf and others 1978). *Eucalyptus robusta* and *E. globulus* were the major eucalypts planted. In 1979, out of a total of 750 ha (1847 acres) of young plantations not inventoried previously on State land on the island of Hawaii, more than 1,656 acres (670 ha) were planted with eucalyptus, most of which were *E. saligna* (Hawaii Div. Forestry 1979).

In recent years, the Forest Service has evaluated most of the older plantings, and also established additional trials to determine species adaptability. Fujii (1976) measured a 64-year-old trial planting of 18 species of eucalyptus in a watershed area above Honolulu. He recommended *E. microcorys, E. muelleriana, E. pilularis,* and *E. tereticornis* as the best of the species tested on this very wet, windy site. Burgan and Wong (1971) evaluated 84 introduced species in an arboretum in the Waiakea Forest Reserve near Hilo. After 10 to 14 years, *Callitris endlicheri, E. deglupta, E. grandis,* and *Flindersia brayleyana* were rated highest for growth and wood utilization potential. Several other eucalypts, including *E. saligna,* also had good growth but were considered less desirable for timber use. Whitesell and Isherwood (1971) tested two native and 12 introduced species on Akaka and Kaiwiki soils on the island of Hawaii. After 7 years, *E. saligna* was one of the more promising species on Akaka soil, but was overtopped and smothered by grass on the Kaiwiki soil. Whitesell (1976) planted seven introduced hardwood species in the Waiakea and Olaa Forest Reserves near Hilo. After 10 years, *E. microcorys, F. brayleyana,* and *Toona ciliata* var. *australis* showed the most promise for timber production. Whitesell and Walters (1976) tested 90 species on various sites on the islands of Kauai, Oahu, Molokai, Maui, and Hawaii. After 4 to 7 years, they rated 10 conifers and 32 hardwood species (including 11 eucalypts) as promising on one or more of 16 sites.

Eucalyptus saligna was selected as the main species for BioEnergy's initial plantations because this species has performed well throughout the Hawaiian Islands (Pickford and LeBarron 1960). In a 5-year-old spacing experiment on Maui, trees in all spacings averaged more than 21 m (70 ft) tall, with average diameters ranging from 15.8 cm (6.2 inches) in the 2.4- by 2.4-m (8- by 8-ft) spacing to 20.1 cm (7.9 inches) in the 4.3- by 4.3-m (14- by 14-ft) spacing (Walters and Schubert 1969). At the age of 10, the trees in the same experiment averaged more than 27 m (90 ft) tall and average diameters ranged from 19.3 cm (7.6 inches) in the narrowest spacing to 26.9 cm (10.6 inches) in the widest spacing (Walters 1973). Also, *E. saligna* coppices well, has a relatively high wood density, and is valuable as wood fiber for paper and particle board (Food Agric. Orgn. 1979).

When the first plantations were established, BioEnergy also began experiments to appraise other tree species that may be useful for biomass production. Between 1979 and 1983, it started nine species introduction trials at five locations on the island of Hawaii *(fig. 1).* Included in these trials are 14 species of eucalypts, 10 legumes, and 4 other species. The trials are laid out at spacings ranging from 1.5 by 1.5 m (5 by 5 ft)

to 2.0 by 2.0 m (6.6 by 6.6 ft), replicated four times in randomized complete block designs. Three to 15 species are included in each trial. With one exception, the design called for at least 100 trees of each species to be measured in each trial, initially. The trees were fertilized at time of planting and again at 6 months, with an NPK fertilizer. They were weeded as necessary during the first 2 years to keep them free of competition.

SITE CONDITIONS AND SPECIES PERFORMANCE

Hamakua Coast

For this area, we selected three test sites—Onomea, Kamae, and Amauulu—along the Hamakua Coast. They lie north of Hilo, on the windward slope of Mauna Kea, at 19°50′ N latitude and 155°10′ W longitude. Elevations range from 425 m (1400 ft) to 490 m (1600 ft); aspect is northeast, with slopes from 4 to 20 percent. Mean annual rainfall is over 5000 mm (200 inches) but totals for any given month vary greatly from year to year. Extended droughts occurred in 1983-1984. The mean monthly temperature in January is 11°C (52°F); in July 19°C (66°F). Under these subtropical conditions, tree growth continues throughout the year.

Onomea

The planting trial at Onomea is on abandoned cane land, at 425 m (1400 ft) elevation. Slopes range from 10 to 20 percent. The soil type is the Akaka silty clay loam (thixotropic isomesic Typic Hydrandept). This soil is moderately well drained and developed from volcanic ash. The surface layer is dark reddish brown, subangular blocky, and about 380 mm (15 inches) thick. The subsoil is a reddish brown, subangular blocky and prismatic silty clay loam over 1.5 m (5 ft) thick. This soil has thixotropic properties and dehydrates irreversibly into fine gravel-size particles. It is very strongly acid, with a pH of 5.0 in the surface layer (0-30 cm [0-12 inches]) and strongly acid (pH of 5.1) in the subsurface layer (30-60 cm [12-24 inches]). The Akaka soil is extremely low in phosphorus, potassium, calcium, and magnesium; is somewhat low in silicon; but is high in iron and aluminum. Its aluminum content may even be toxic for some plants.

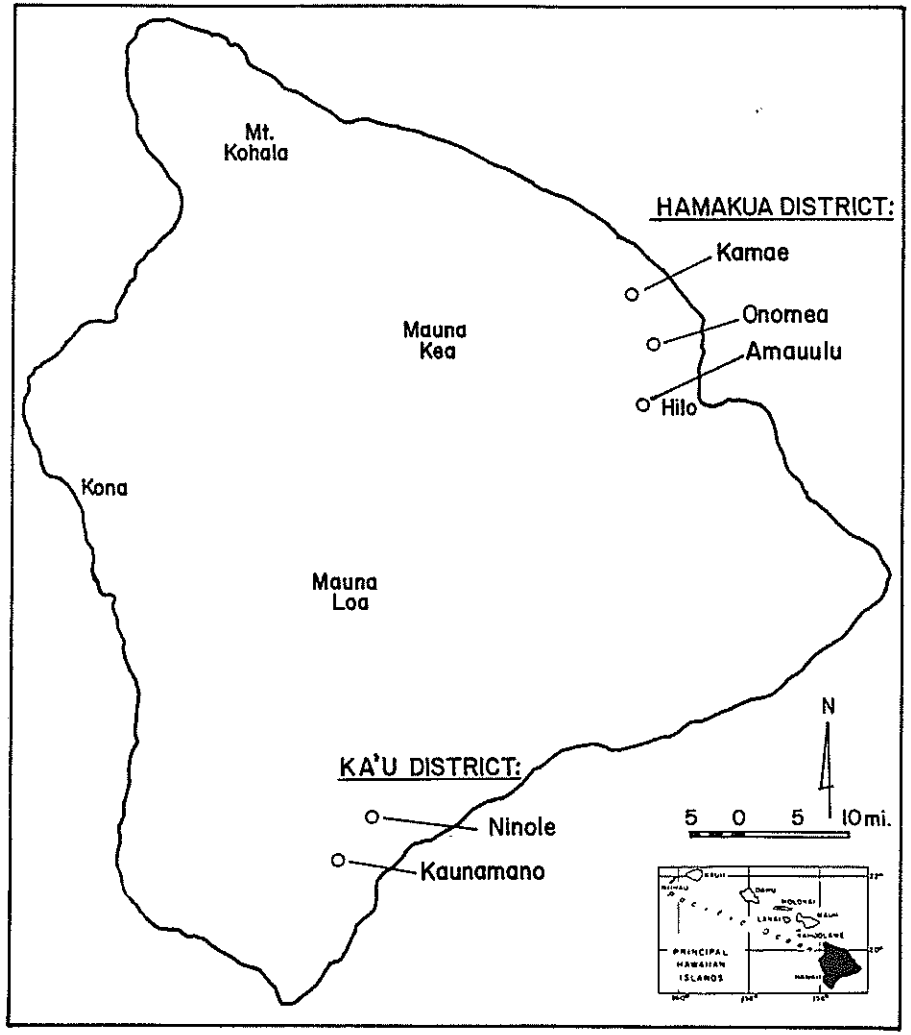

Figure 1—BioEnergy Development Corporation's eucalyptus planting sites on the Island of Hawaii.

Four of the eight eucalyptus species tested and *Albizia falcataria* appeared promising after 5 years *(table 1, fig. 2).*[1] The albizzia slightly outgrew *E. saligna* in height on

[1]Tables 1-10 and figures 2-8 are in the *appendix.*

this low quality site until recently. *Eucalyptus robusta, E. urophylla,* and *E. grandis* also performed well, but expressed slower diameter growth than did the albizzia and the saligna. Survival for these five species ranged from 78 to 97 percent. Their mean annual growth was 2.5 m (8 ft) or greater. Survival of *E. globulus* was only 62 percent, otherwise its performance was satisfactory. *Eucalyptus citriodora* failed, probably because the planting stock was of poor quality.

Kamae

The five species trials at Kamae are at 500 m (1600 ft) elevation. The soil type is the Akaka silty clay loam, with the same characteristics as described for the Onomea site. These trials are mostly on abandoned cane land or on sites classified as "wasteland," that is, unsuitable for cane production.

Trial 1—Acacia mangium outperformed 10 eucalyptus species on this poor site, after 4.5 years, averaging nearly 14 m (46 ft) in height *(table 2, fig. 3).* This introduced species is proving superior on this very acidic, high rainfall area, producing excellent diameter growth and high survival. Three eucalypts—*E. urophylla, E. robusta,* and *E. grandis*—are promising. However, survival was less than 65 percent for eight of the species tested.

Trial 2—The two eucalyptus and three legume species planted on this poorly drained swampy site performed satisfactorily after 36 months *(table 3, fig. 4). Albizia falcataria* has grown best here, although *Eucalyptus saligna,* which has grown much better here than in Kamae Trial 1, is not far behind. *Acacia mangium* tends to be multi-stemmed on this site, whereas a different seedlot produced mostly single stems in Kamae Trial 1.

Locally, *E. robusta* is the species usually planted on poorly drained sites; here it had a survival of 86 percent, compared to 88 percent for the albizzia.

Trial 3—Three eucalyptus and three legume species were tested on a well drained slope *(table 4, fig. 5). Eucalyptus saligna* has grown the best here after 36 months, followed by *E. robusta, E. globulus,* and *Albizia falcataria.* All four of these species grew better here than on the poorly drained site at Kamae Trial 2. However, survival of *E. globulus* was only 62 percent. *Acacia melanoxylon* did not grow as well here as it did in Kamae Trial 2. *Acacia mangium* grew about the same on both sites, and is also multi-stemmed here.

Trial 4—Eucalyptus grandis, Casuarina equisetifolia, and *Gmelina arborea* were planted in July 1981, on this average quality site. *Eucalyptus grandis* grew very well, with high survival (94 pct), but after 36 months the other two species were considered unsatisfactory, with poor vigor and low survival *(table 5).*

Trial 5—Three eucalyptus species, *Mimosa scabrella,* and the native *Acacia koa,* were planted in July 1983, on an average quality site *(table 6).* All three eucalypts have grown well here, after 24 months, averaging more than 2.5 m (8 ft) height growth per year. Growth and survival of the two legume species were unsatisfactory.

Amauulu

This species trial is on former scrub forest land at 490 m (1,600 ft) elevation. The soil type is the Kaiwiki silty clay loam (thixotropic isothermic Typic Hydrandept), a soil similar to the related Akaka series but lacking a faint mottling in the B horizon of the Akaka soil. It is very strongly acid (pH 4.8 to 5.0). Levels of soil calcium are low (26-112 ppm).

Two eucalyptus, five legumes, and three other species were planted in September 1981, on a below average site *(table 7, fig. 6).* Although *Mimosa scabrella* made the best growth here after 12 months, *E. saligna* and *E. robusta* are now taller and have larger diameters, after 36 months. *Mimosa scabrella* actually is failing on this site—the tops of many trees have died back and survival is only 28 percent. *Acacia mangium* again tends to be multi-stemmed. *Sesbania grandiflora, S. sesban,* and *Leucaena leucocephala* failed here. *Gmelina arborea, Lippia toresii,* and *Pinus elliottii* have also proved not adapted to this poor site.

Ka'u District

BioEnergy Development Corporation has experimental plantings at two sites in the Ka'u District, located in the drier, southern part of the Island of Hawaii. These sites are situated on the southern flank of Mauna Loa, an active volcano.

Ninole

The Ninole Valley species trial is 9.6 km (6 miles) southwest of Pahala, at 19° 10′ N latitude and 155°33′ W longitude. This trial is on recently abandoned cane land, at 550 m (1800 ft) elevation. Mean annual rainfall is 1800 mm (70 inches) with a dry season during the summer months. Slopes range from 6 to 20 percent. The trial is on two adjacent soil types; one is Alapai extremely stony silty clay loam (thixotropic isothermic Typic Hydrandept), the other is Kiloa extremely stony muck (dysic isothermic Typic Tropofolist).

The Alapai series consists of well-drained silty clay loams formed from volcanic ash. This soil is 500 to 750 mm (20 to 30 inches) deep over Aa lava. Stones cover 3 to 15 percent of the surface. The surface layer is very strongly acid and the subsoil is strongly acid (pH 5.2 to 5.5). This soil dehydrates irreversibly into fine gravel-size aggregates.

The Kiloa series consists of well-drained, thin, extremely stony organic soils over fragmental Aa lava. The surface layer is a stony muck.

The two trials at Ninole are on younger soils than those on the Hamakua Coast. Soils here have moderately high levels of phosphorus, potassium, calcium, and magnesium.

Four eucalyptus and one legume species were planted on each of the two adjacent soils *(tables 8 and 9, figs. 7 and 8).* Unfortunately, a severe storm caused windthrow and broken stems when the trees were 20 months old. The most severely damaged species was *E. botryoides;* next most was *E. microcorys.* Some *E. citriodora* and *E. saligna* had leaning stems but recovered well. *Acacia mangium* suffered some defoliation but little other damage. Fallen and broken trees were removed after the storm to prevent disease or insect problems. Although all species have made acceptable growth in 54 months, we recommend that *E. botryoides* and *E. microcorys* not be planted here because of their susceptibility to wind damage. In comparing species performance on the two sites, we found no real differences in growth among the eucalypts.

Kaunamano

The species trial is on recently abandoned cane land about 1 mile north of Naalehu, at latitude 19°05′N, and longitude 155°36′W. The elevation is 650 m (2160 ft); with slopes from 3 to 15 percent. Mean annual rainfall is 2300 mm (90 inches); with a dry season during the summer months. The soil is Alapai extremely stony silty clay loam, which is described above.

Ten eucalyptus and five legume species were tested on an average quality site *(table 10). Eucalyptus saligna* and *E. grandis* made equally superior growth, averaging more than 4 m (13 ft) in height growth annually during the first 2 years. The leguminous species have all grown relatively slowly; even the albizzia averaged only 2.5 m (8 ft) per year in height growth. The three acacias and *Mimosa scabrella* had unsatisfactory survival. More time must pass before we can adequately appraise these species performances.

CONCLUSIONS

The anticipated rotation age for BioEnergy's plantations is 6 years (perhaps longer). In species trials, the successful candidates can usually be identified by the fourth year. However, relative performances can undergo rapid changes throughout the rotation. For example, at Onomea, *Albizia falcataria* had the best height growth at 36 months, but at 60 months, *Eucalyptus saligna* has surpassed it. Likewise, at Amauulu, *Mimosa scabrella* had the best height growth at 12 months, but at 36 months it was dying back, having been overtaken by *E. saligna, E. robusta,* and *Acacia mangium.*

Because only three of our trials are over 4 years of age, insufficient time has elapsed to permit final evaluations. However, some tentative conclusions can be drawn. *Eucalyptus grandis* has outgrown *E. saligna* in most of the trials where it has been planted, and the results of the provenance tests indicate that it produces more volume than *E. saligna* and thus should be preferred if seed of high-yield producing provenances can be obtained. However, *E. saligna* is consistently one of the best species in the trials, except at Kamae Trial 1 (which may be due to the seed source used there). Thus it appears to be a good overall choice for planting on sites similar to the test sites. Exceptions would be poorly-drained sites or sites with very shallow soils. *Eucalyptus saligna* yields could be increased if the best seed sources, identified in our ongoing provenance trials, are used instead of locally collected seed. *Eucalyptus globulus* and *E. robusta* have also grown well in several trials. The *E. globulus* does best at higher elevations and on well drained soils. *Eucalyptus robusta* usually thrives on poorly drained sites, although at Kamae Trial 2, it was one of the poorer species tested.

Among the other species appraised, *Albizia falcataria* has done the best, but it tends to branch excessively and often has multiple stems which may make it difficult to harvest. It also has low specific gravity (about half that of eucalyptus) which reduces its value for fuel. Thus it may be most useful as a nitrogen-fixing species to interplant with the eucalypts. *Acacia mangium* grew well with good form in Kamae Trial 1, but in the other trials it produced multiple stems. Thus its usefulness depends on finding a seed source with good growth and single stems, as the North Queensland, Australia source used in Kamae Trial 1 is unfortunately no longer available. *Mimosa scabrella* is another nitrogen-fixing species which had shown some promise, but after an initial spurt of growth it is now dying back. Wet soils are reputed to stunt the growth of this species (Nat. Acad. Sci. 1980), so perhaps the test sites are too wet for its continued development. A provenance test comparing seven sources of *M. scabrella* from Brazil was started in January 1983 to help determine whether this species has potential either for biomass or for interplanting with the eucalypts on our sites.

APPENDIX

Onomea

Table 1—*Performance of 10 species planted at Onomea, Hawaii Island, evaluated after 60 months*

Species and source	Trees planted	Height			Dbh[4]	Survival
		Average[3]	Range	Annual growth		
		meters			*cm*	*pct*
Eucalyptus saligna[1]	64	13.9a	3-24	2.8	10.0a	86
Albizia falcataria[1]	64	13.2ab	7-14	2.6	10.4a	97
Eucalyptus robusta[1]	64	12.7ab	4-19	2.5	9.1a	92
Eucalyptus grandis						
Commercial	64	12.6ab	4-23	2.5	9.0a	79
Eucalyptus urophylla						
Timor, Indonesia	64	12.5ab	2-23	2.5	9.6a	78
Eucalyptus globulus[1]	48	12.0ab	4-20	2.4	7.0ab	62
Acacia melanoxylon						
Commercial	64	8.8 b	2-14	1.8	7.2ab	56
Eucalyptus dunnii						
New South Wales, Australia	64	8.8 b	3-18	1.8	6.8ab	69
Eucalyptus camaldulensis[1]	32	8.7 b	4-17	1.7	4.9 b	81
Eucalyptus citriodora[1]	64	(2)—	—	—	—	—

[1]Source: Island of Hawaii.

[2]Failed.

[3]Minimum significant difference equals 4.9626, using the harmonic mean of the cell sizes. Means with the same letters are not significantly different (5 pct level).

[4]Minimum significant difference equals 4.0123, using the harmonic mean of the cell sizes. Means with the same letters are not significantly different (5 pct level).

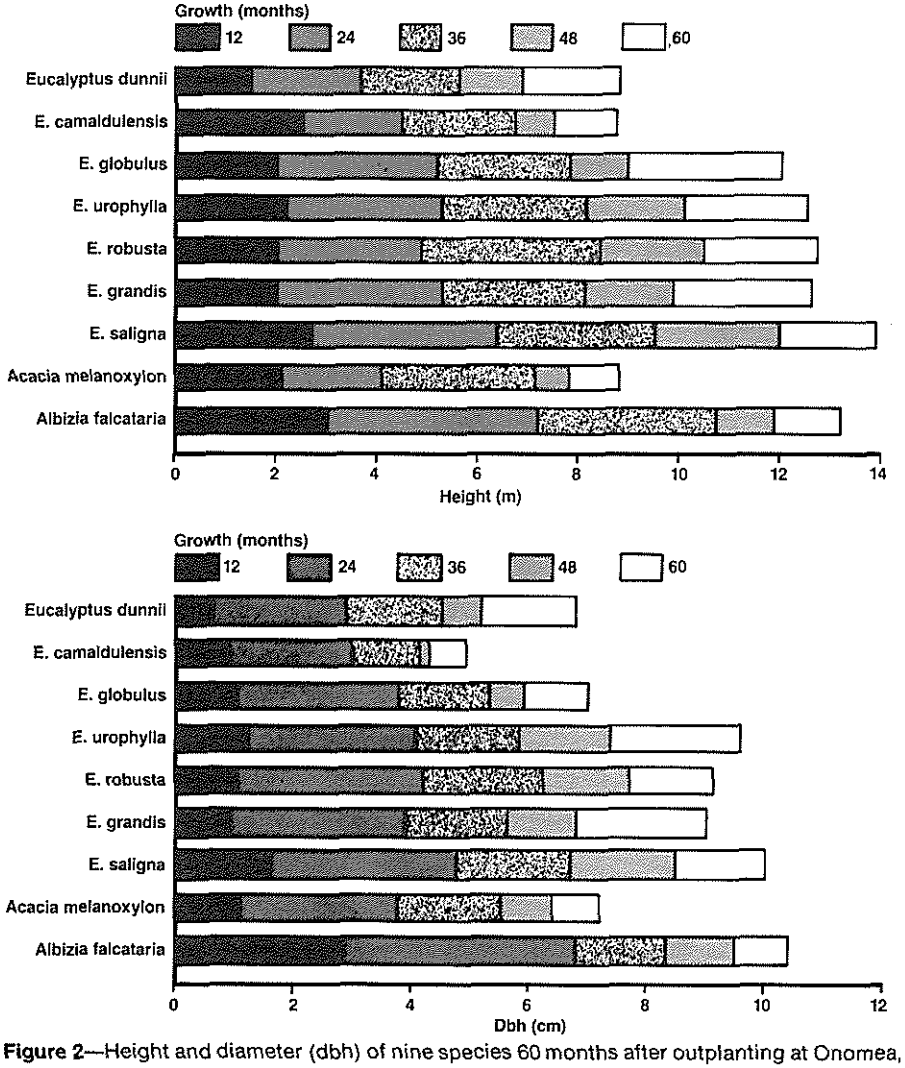

Figure 2—Height and diameter (dbh) of nine species 60 months after outplanting at Onomea, Hawaii Island.

Kamae—Trial 1

Table 2—*Performance[1] of 11 species planted at Kamae—Trial 1, Hawaii Island, evaluated after 54 months*

Species and source	Height			Dbh[4]	Survival[5]
	Average[3]	Range	Annual growth		
	meters			*cm*	*pct*
Acacia mangium					
N. Queensland, Australia	13.7a	10-16	3.0	10.4a	95a
Eucalyptus urophylla					
E. Timor, Indonesia	12.2ab	5-19	2.7	7.8abc	81ab
Eucalyptus grandis					
Queensland, Australia	12.0ab	2-22	2.7	8.1ab	62 bcd
Eucalyptus robusta[2]	10.8abc	5-15	2.4	7.6 bc	78abc
Eucalyptus saligna[2]	9.5 bcd	4-17	2.1	7.6 bc	48 cd
Eucalyptus viminalis					
Victoria, Australia	8.9 bcd	5-14	2.0	6.5 bcd	36 d
Eucalyptus maidenii					
Unknown	8.6 bcd	4-18	1.9	6.0 bcd	50 bcd
Eucalyptus dunnii					
New South Wales, Australia	8.2 cd	4-15	1.8	5.5 bcd	65abcd
Eucalyptus microcorys					
Kauai Island, Hawaii	8.1 cd	2-16	1.8	4.8 d	52 bcd
Eucalyptus botryoides					
Uruguay	8.0 cd	4-18	1.8	6.6 bcd	48 cd
Eucalyptus nitens					
New South Wales, Australia	6.2 d	4-14	1.4	5.2 cd	39 d

[1]Basis: 100 trees per species initially planted.
Means with the same letters are not significantly different (5 pct level).
[2]Source: Island of Hawaii.
[3]Minimum significant difference equals 3.6976, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 2.7019, using the harmonic mean of the cell sizes.
[5]Minimum significant difference equals 31.236, using the harmonic mean of the cell sizes.

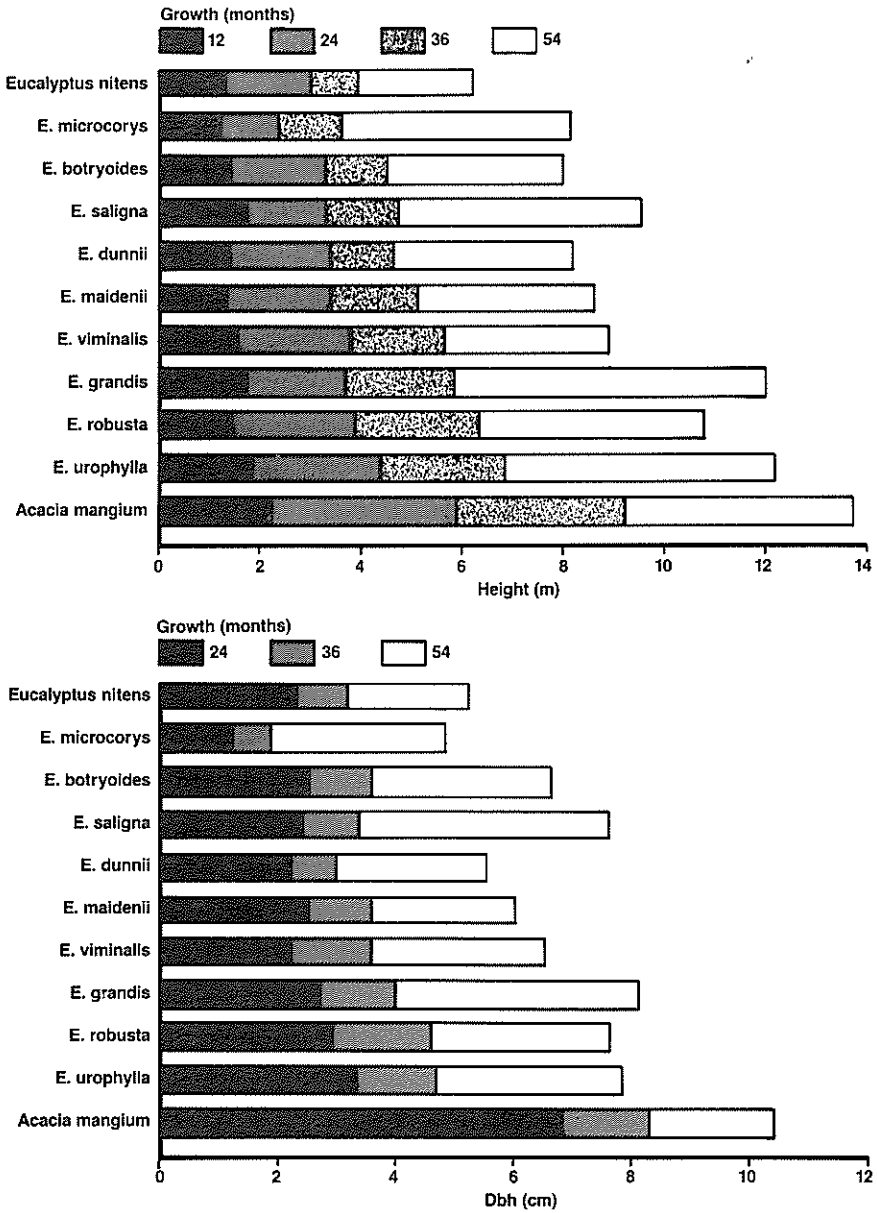

Figure 3—Height and diameter (dbh) of 11 species 54 months after outplanting at Kamae, Hawaii Island.

Kamae—Trial 2

Table 3—*Performance*[1] *of 5 species planted at Kamae—Trial 2, Hawaii Island, evaluated after 36 months*

Species and source	Height			Dbh[3]	Survival[4]
	Average[2]	Range	Annual growth		
	meters			*cm*	*pct*
Albizia falcataria					
Hawaii Island, Hawaii	10.4a	3-15	3.5	8.4a	88
Eucalyptus saligna					
Hawaii Island, Hawaii	10.0ab	4-14	3.3	7.3ab	86
Acacia mangium					
Sabah, Malaysia	8.9ab	3-12	3.0	7.0ab	75
Eucalyptus robusta					
Hawaii Island, Hawaii	7.0 b	3-13	2.3	6.6ab	86
Acacia melanoxylon					
Commercial	6.9 b	2-10	2.3	5.9 b	69

[1]Basis: 100 trees per species initially planted
Means with the same letters are not significantly different (5 pct level).
[2]Minimum significant difference equals 3.1583, using the harmonic mean of the cell sizes.
[3]Minimum significant difference equals 2.2148, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 19.94, using the harmonic mean of the cell sizes.

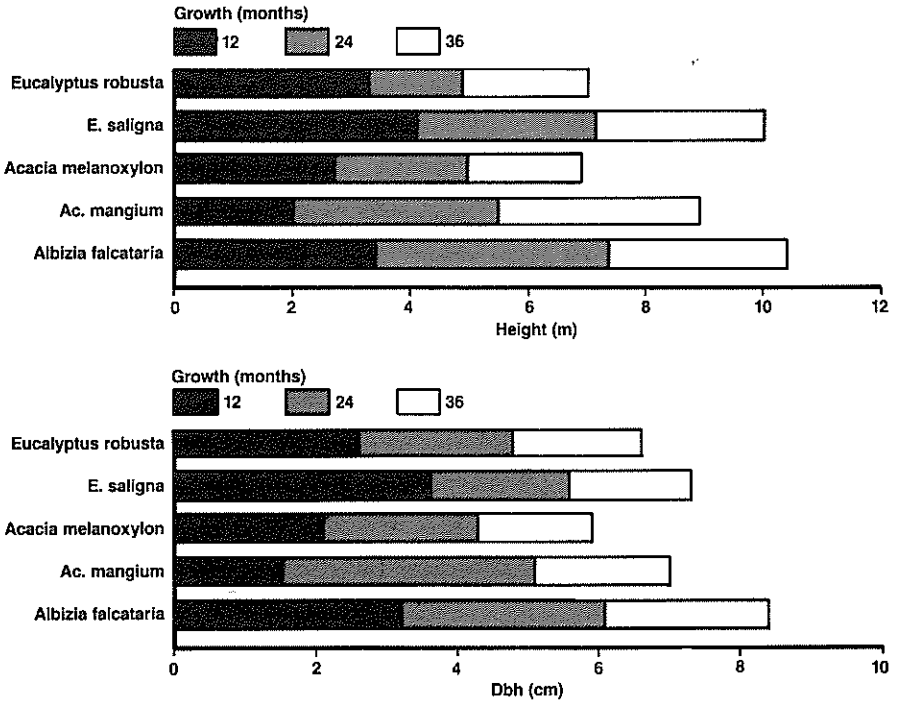

Figure 4—Height and diameter (dbh) of five species 36 months after outplanting at Kamae, Hawaii Island.

Kamae—Trial 3

Table 4—*Performance*[1] *of six species planted at Kamae—Trial 3, Hawaii Island, evaluated after 36 months*

Species and source	Height			Dbh[3]	Survival[4]
	Average[2]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus saligna					
Hawaii Island, Hawaii	15.9a	9-20	5.3	9.7a	89a
Eucalyptus robusta					
Hawaii Island, Hawaii	12.5 b	8-15	4.2	9.1ab	93a
Eucalyptus globulus					
Hawaii Island, Hawaii	12.3 b	6-17	4.1	8.0 bc	62 b
Albizia falcataria					
Hawaii Island, Hawaii	12.2 b	4-16	4.1	8.8ab	88a
Acacia mangium					
Sabah, Malaysia	9.6 c	7-12	3.2	6.7 c	89a
Acacia melanoxylon					
Commercial	5.9 d	3-10	2.0	4.6 d	52 b

[1]Basis: 100 trees per species initially planted.
Means with the same letters are not significantly different (5 pct level).
[2]Minimum significant difference equals 1.8454, using the harmonic mean of the cell sizes.
[3]Minimum significant difference equals 1.4201, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 25.125, using the harmonic mean of the cell sizes.

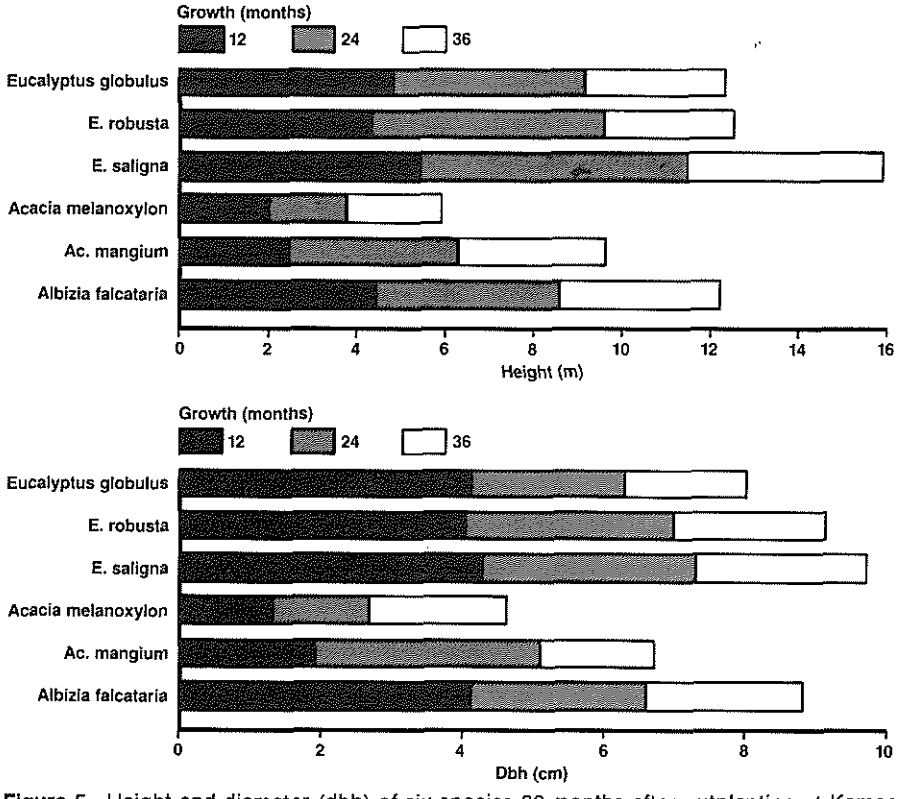

Figure 5—Height and diameter (dbh) of six species 36 months after outplanting at Kamae, Hawaii Island.

Kamae—Trial 4

Table 5—*Performance*[1] *of three species planted at Kamae—Trial 4, Hawaii Island, evaluated after 36 months*

Species	Height			Dbh[3]	Survival[4]
	Average[2]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus grandis	11.7a	2-16	3.9	7.0a	94a
Casuarina equisetifolia	2.9 b	1-7	1.0	1.2 b	58 b
Gmelina arborea	1.9 b	1-3	0.6	1.5 b	56 b

[1]Basis: 100 trees per species initially planted.
Means with the same letters are not significantly different (5 pct level).
[2]Minimum significant difference equals 1.830, using the harmonic mean of the cell sizes.
[3]Minimum significant difference equals 0.81303, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 37.762, using the harmonic mean of the cell sizes.

Kamae—Trial 5

Table 6—*Performance*[1] *of five species planted at Kamae—Trial 5, Hawaii Island, evaluated after 24 months*

Species and source	Height			Dbh[3]	Survival[4]
	Average[2]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus saligna					
Island of Hawaii	5.4a	2-10	2.7	4.7a	97a
Eucalyptus urophylla					
Mixed sources	5.0a	2-9	2.5	4.7a	90a
Eucalyptus camaldulensis					
Mixed sources	5.0a	2-9	2.5	3.8a	94a
Mimosa scabrella					
Parana, Brazil	3.8a	1-6	1.9	2.9a	32 c
Acacia koa					
Island of Hawaii	3.2a	1-8	1.6	3.1a	49 b

[1]Basis: 144 trees per species initially planted.
Means with the same letters are not significantly different (5 pct level).
[2]Minimum significant difference equals 2.3448, using the harmonic mean of the cell sizes.
[3]Minimum significant difference equals 1.9485, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 16.233, using the harmonic mean of the cell sizes.

Amauulu

Table 7—*Performance*[1] *of 10 species planted at Amauulu, Hawaii Island, evaluated after 36 months*

Species	Height			Dbh[4]	Survival[5]
	Average[3]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus saligna	10.8a	5-16	3.6	10.2a	96a
Eucalyptus robusta	9.2ab	4-14	3.1	10.2a	98a
Mimosa scabrella	6.9 bc	4-10	2.3	5.7 b	28 cd
Acacia mangium	5.9 bc	3-8	2.0	6.6ab	94ab
Lippia toressi	(2)	—	—	—	—
Gmelina arborea	(2)	—	—	—	—
Pinus elliottii	(2)	—	—	—	—
Leucaena leucocephala	(2)	—	—	—	—
Sesbania grandiflora	(2)	—	—	—	—
Sesbania sesban	(2)	—	—	—	—

[1]Basis: 50 trees per species initially planted.
Means with the same letters are not significantly different (5 pct level).
[2]Failed.
[3]Minimum significant difference equals 3.9381, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 3.645, using the harmonic mean of the cell sizes.
[5]Minimum significant difference equals 39.651, using the harmonic mean of the cell sizes.

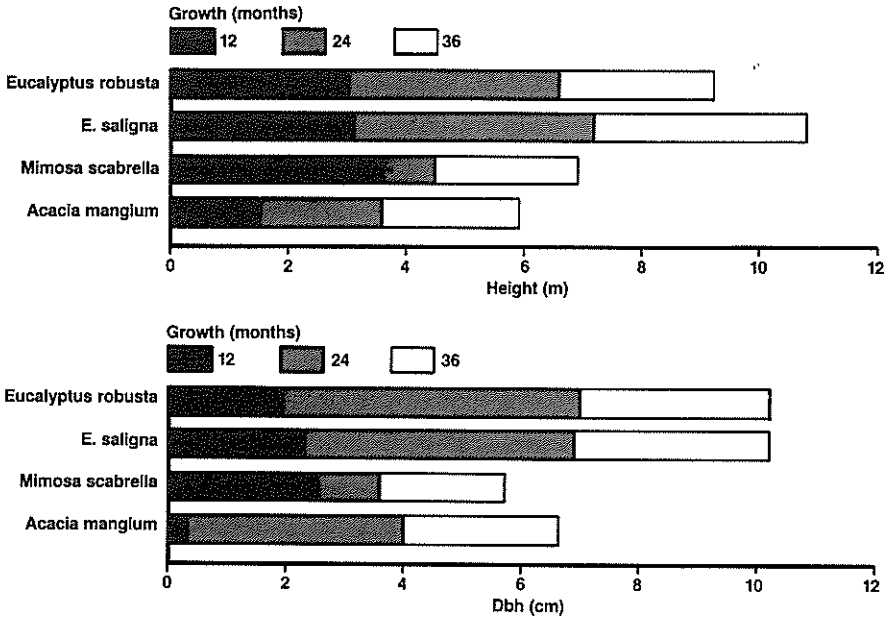

Figure 6—Height and diameter (dbh) of eight (8) species 36 months after outplanting at Amauulu, Hawaii Island.

Ninole—Kiloa Soil

Table 8—*Performance*[1] *of five species planted on Kiloa soil at Ninole, Ka'u, Hawaii Island, evaluated after 54 months*

Species and source	Height			Dbh[3]	Survival[4]
	Average[2]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus saligna					
Maui Island, Hawaii	10.9a	3-20	2.4	7.4a	87a
Eucalyptus microcorys					
Kauai Island, Hawaii	11.0a	3-20	2.4	7.2a	58 b
Eucalyptus citriodora					
Hawaii Island, Hawaii	10.0ab	4-16	2.2	7.1a	84a
Eucalyptus botryoides					
Uruguay	10.5ab	4-18	2.3	7.6a	61ab
Acacia mangium					
Queensland, Australia	8.5 b	3-11	1.9	7.1a	85a

[1]Basis: 100 trees per species initially planted, except for *E. botryoides* with 75 trees planted. Means with the same letters are not significantly different (5 pct level).
[2]Minimum significant difference equals 2.1525, using the harmonic mean of the cell sizes.
[3]Minimum significant difference equals 1.9017, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 25.817, using the harmonic mean of the cell sizes.

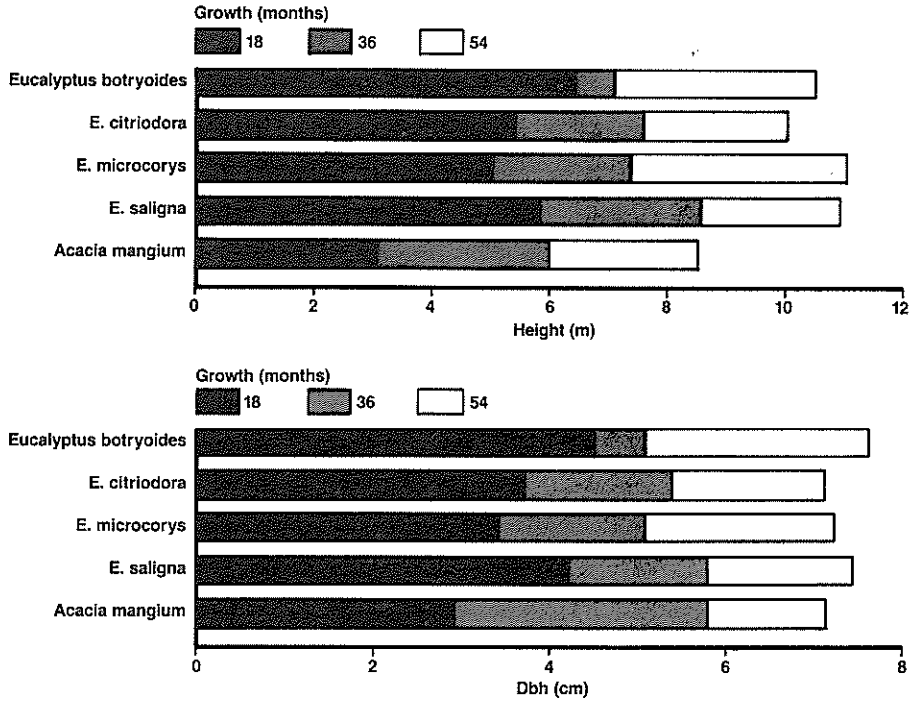

Figure 7—Height and diameter (dbh) of five species 54 months after outplanting on Kiloa soil at Ninole, Ka'u, Hawaii Island.

Ninole—Alapai Soil

Table 9—*Performance[1] of five species planted on Alapai soil at Ninole, Ka'u, Hawaii Island, evaluated after 54 months*

Species and source	Height			Dbh[3]	Survival[4]
	Average[2]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus microcorys					
Kauai Island, Hawaii	10.1a	3-18	2.2	6.1 b	89a
Eucalyptus saligna					
Maui Island, Hawaii	9.9a	3-20	2.2	6.6ab	87a
Eucalyptus citriodora					
Hawaii Island, Hawaii	9.3a	4-16	2.1	6.1 b	80a
Eucalyptus botryoides					
Uruguay	8.9a	3-20	2.0	5.6 b	77a
Acacia mangium					
Queensland, Australia	9.3a	5-12	2.1	8.0a	81a

[1]Basis: 100 trees per species initially planted, except for *E. botryoides* with 75 trees planted. Means with the same letters are not significantly different (5 pct level).
[2]Minimum significant difference equals 2.2212, using the harmonic mean of the cell sizes.
[3]Minimum significant difference equals 1.746, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 20.892, using the harmonic mean of the cell sizes.

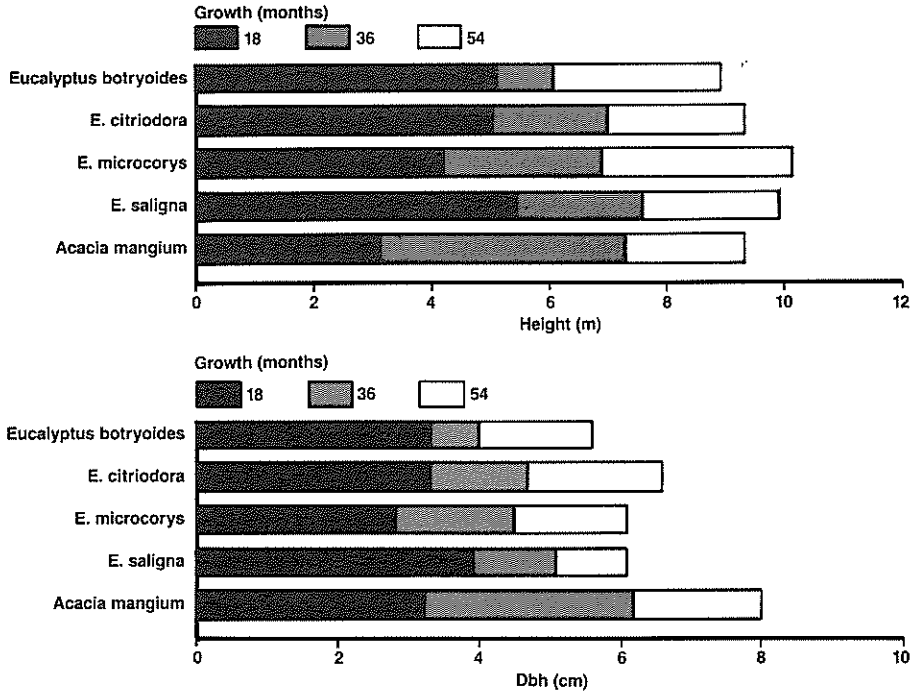

Figure 8—Height and diameter (dbh) of five species 54 months after outplanting on Alapai soil at Ninole, Ka'u, Hawaii Island.

Kaunamano

Table 10—*Performance[1] of 15 species planted at Kaunamano, Ka'u, Hawaii Island, evaluated after 23 months*

Species and source	Height			Dbh[4]	Survival[5]
	Average[3]	Range	Annual growth		
	meters			*cm*	*pct*
Eucalyptus saligna					
Hawaii Island, Hawaii	8.1a	2-10	4.2	6.7a	94a
Eucalyptus grandis					
New South Wales, Australia	7.8a	2-11	4.1	6.7a	92a
Eucalyptus globulus					
Hawaii Island, Hawaii	7.3ab	2-11	3.8	6.3ab	81ab
Eucalyptus viminalis					
Victoria, Australia	6.6abcd	3-11	3.4	5.7abc	81ab
Eucalyptus urophylla					
Flores, Indonesia	6.4abcde	2-10	3.3	5.6abc	90a
Eucalyptus nitens					
Victoria, Australia	7.1abc	3-10	3.7	7.0a	65abc
Eucalyptus tereticornis					
Nigeria, West Africa	5.6 bcde	2-8	2.9	4.5 bcd	91a
Eucalyptus camaldulensis					
New South Wales, Australia	5.1 def	2-8	2.7	3.8 cde	94a
Eucalyptus robusta					
Queensland, Australia	5.4 cde	2-8	2.8	5.1abcd	93a
Eucalyptus citriodora					
Queensland, Australia	4.6 efg	2-8	2.4	3.7 cde	66abc
Albizia falcataria					
Sri Lanka	4.8 def	3-6	2.5	6.1ab	85ab
Acacia confusa					
Taiwan, Republic of China	2.8 h	2-4	1.5	2.2 e	69abc
Acacia auriculaeformis					
India[2]	2.9 gh	2-4	1.5	2.1 e	56 bc
Acacia mangium					
Queensland, Australia[2]	2.9 gh	2-4	1.5	3.3 de	47 cd
Mimosa scabrella					
Parana, Brazil	3.4 fgh	2-5	1.8	2.4 e	18 d

[1]Basis: 144 trees per species initially planted.
Means with the same letters are not significantly different (5 pct level).
[2]Commercial source.
[3]Minimum significant difference equals 1.85758, using the harmonic mean of the cell sizes.
[4]Minimum significant difference equals 2.09165, using the harmonic mean of the cell sizes.
[5]Minimum significant difference equals 30.4763, using the harmonic mean of the cell sizes.

REFERENCES

Burgan, Robert E.; Wong, Wesley H. C. **Species trials at the Waiakea Arboretum . . . tree measurements in 1970.** Res. Note PSW-240. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1971. 6 p.

Food and Agriculture Organization of the United Nations. **Eucalypts for planting.** FAO Forestry Series No. 11. 1979; 677 p.

Fujii, David M. **The Nuuanu eucalyptus planting: growth, survival, stand development after 64 years.** Res. Note PSW-318. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976. 5 p.

Hawaii Division of Forestry. **Forest plantation survey, Biomass energy treefarm program.** Honolulu, Hawaii. 1979; 22 p.

LeBarron, R.K. **Eucalypts in Hawaii: a survey of practices and research programs.** Misc. Paper 64. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1962. 24 p.

Metcalf, Melvin E.; Nelson, Robert E.; Petteys, Edwin P.; Berger, John M. **Hawaii's Timber Resources 1970.** Resour. Bull. PSW-15, Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1978. 20 p.

National Academy of Sciences. **Firewood crops. Shrub and tree species for energy production.** Washington, DC. 1980. 237 p.

Pickford, G. D.; LeBarron, R. K. **A study of forest plantations for timber production on the island of Hawaii.** Tech. Paper 52. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1960. 17 p.

Walters, Gerald A. **Growth of saligna eucalyptus—A spacing study after ten years.** J. For. 71(6):346-348; 1973.

Walters, Gerald A.; Schubert, Thomas H. **Saligna eucalyptus growth in a 5-year-old spacing study in Hawaii.** J. For. 67(4):232-234; 1969.

Whitesell, Craig D. **Performance of seven introduced hardwood species on extremely stony mucks in Hawaii.** Res. Note PSW-309. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976. 5 p.

Whitesell, Craig D.; Isherwood, Jr., Myron O. **Adaptability of 14 tree species to two Hydrol Humic Latosol soils in Hawaii.** Res. Note PSW-236. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1971. 5 p.

Whitesell, Craig D.; Walters, Gerald A. **Species adaptability trials for man-made forests in Hawaii.** Res. Paper PSW-118. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976. 30 p.

The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry. *It carries out this role through four main activities:*

- Protection and management of resources on 191 million acres of National Forest System lands.
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands.
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas.
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Forest and Range Experiment Station

- Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

Schubert, Thomas, H.; Whitesell, Craig D. **Species trials for biomass plantations in Hawaii: a first appraisal.** Res. Paper PSW-176. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1985. 13 p.

Fast-growing trees producing high-density wood are required to justify from an economic standpoint short rotation biomass plantations. Nine species trials were established on five sub-tropical sites on the island of Hawaii. Survival and growth of 27 introduced species and the native *Acacia koa* were appraised at one or more locations, for periods from 24 to 60 months. Performance varied greatly, within, and between all species tested. *Eucalyptus saligna* and *E. grandis* usually proved to be the species best adapted to well drained sites. Most failures and unsatisfactory performances related to harsh site conditions, such as low soil fertility, droughts, and high winds.

Retrieval Terms: Eucalyptus, Albizia, Acacia, species trials, biomass, subtropical, Polynesia, Hawaii.